Effect of Various Wire Electrodes' Material on Cutting Rate of D3 Material

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Abstract—*Wire electrical discharge machining (WEDM) is extensively used in machining of conductive materials when precision is of prime importance. In this study, the effect of the different electrode materials on performance characteristics i.e. cutting rate and cutting time were investigated. The experiments were conducted under the constant cutting parameters of T_{ON}, T_{OFF}, I_P, W_P, W_F, W_T, S_V. For the experiment, three wires are chosen on the basis of their maximum usage as a wire electrode in WEDM. These three wires are Brass wire, zinc coated copper wire and Steel wire coated with primary coating of Copper and secondary coating of Zinc. These wires of 0.25mm diameter are operated on the D_3 work piece material having thickness of 20mm and results are compared in the present investigation. The performance parameters which are compared in this study are cutting speed and cutting time. During the experimentation, it has been found that the cutting speed is maximum in case of Steel wire coated with Cu and Zn as compared to brass and zinc coated copper wire.*

Keywords: -Wire electrical discharge machining, brass wire, zinc coated copper wire, steel wire, cutting speed, cutting time.

I. INTRODUCTION

Wire Electro-discharge Machining (WEDM) is an adaptation of the basic EDM process, which can be used for cutting complex two- and three-dimensional shapes through electrically conducting materials. WEDM utilizes a thin, continuously moving wire as an electrode referring to Figure 1. It is a relatively new process and applications have grown rapidly particularly in the tool making field. The wire electrode is drawn from a supply reel and collected on a take-up reel. This continuously delivers fresh wire to the work area. The wire is guided by sapphire or diamond guides and kept straight by high tension, which is important to avoid tapering of the cut surface [1]. High-frequency dc pulses are delivered to the wire and workpiece, causing spark discharges in the narrow gap between the two. A stream of dielectric fluid is directed, usually coaxially with the wire, to flood the gap between the wire and the workpiece. The power supplies for the WEDM are essentially the same as for conventional EDM, except the current carrying capacity of the wire limits current to less than 20 A, with 10 A or less being most normal. In addition, the spark frequencies are higher up to 1 MHz, to give a fine surface finish on the workpiece [2]. The workpiece is moved under computer numerical control (CNC) relative to the wire, and this enables complex-shaped profiles to be cut through sheet and plate materials. Many machines incorporate further angular positioning of the wire, thus, allowing varying degrees of taper on the cut surface to be obtained. Adaptive control, based on gap-voltage sensing, is necessary to avoid contact between the wire and the work material. Short circuits must be sensed and the wire backed off along the programmed path to reestablish the correct gap for efficient cutting [4, 13].

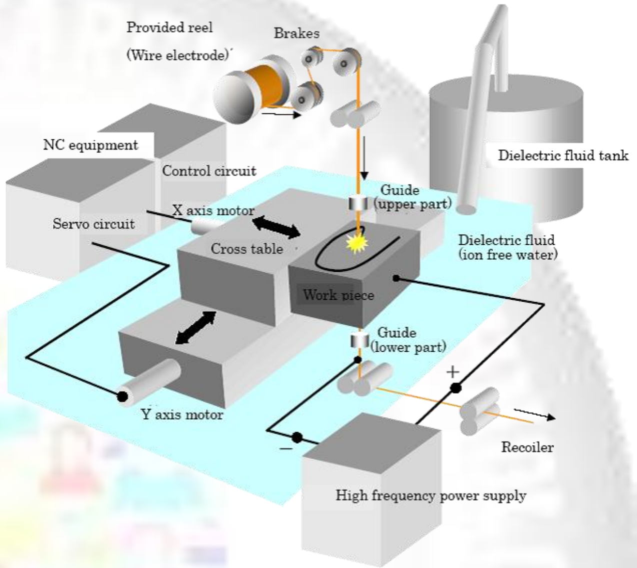


Fig. 1: Schematic Diagram of WEDM Process [2]

During machining, there is no direct contact between the wire and work piece. The wire is always kept in tension so as to avoid the inaccuracy during the cutting process. In addition, the WEDM process is able to machine exotic and high strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels. The material and the wire play a vital role in obtaining the desired surface characteristics during machining. These factors include electrical parameters, dielectric fluid, work piece materials, as well as others. Most related research found that the roughness of WEDMed surfaces increased accompanying the increase of discharge energy [1]. However, along with the recent diversification in applications and fields, demand is expanding for a wire electrode with performance superior to the conventional brass wire electrode. The performance requirements of the electric discharge machine are roughly divided into two groups: One relates to the improvement of machinability of the workpieces, such as electric discharge machining speed, accuracy of form, accuracy of surface, etc., and the other relates to the machinability and economy of the electric discharge machining, such as improvement of automatic threading to cope with unattended operation and cost-cutting. To realize the high-speed and high-precision machining through improvement of the electric discharge machining performance, it is necessary, in combination with increasing the concentration of zinc and increasing the electrical conductivity of the wire electrode, to employ such measures as increasing the temperature strength through improvement of thermal resistance. Moreover, to improve machinability and economy of electric discharge machining, straightness of the wire electrode, aiming at better automatic threading and draw wire machinability, is necessary to respond to the recent trend toward more unattended operations.[6]

A. Properties Requiremnts For A Wire Electrode

Generally, wire electrodes should satisfy the following requirements: (i) accurate machining, (ii) high cutting speed for high productivity, and (iii) automatic threading to allow automation. Figure 2 summarizes the performance requirements for a wire electrode. The electric discharge must be stable for high-precision machining and high energy for high-speed cutting. The three requirements for high-speed cutting and high precision machining are: (i) mechanical strength at high temperatures for good heat resistance, (ii) high electrical conductivity for good calorification resistance, and (iii) high heat conductivity for efficient heat release. In addition, the wire electrodes have to be very straight to allow automatic threading and they need improved drawability and stability during commercial production to achieve good cost performance.

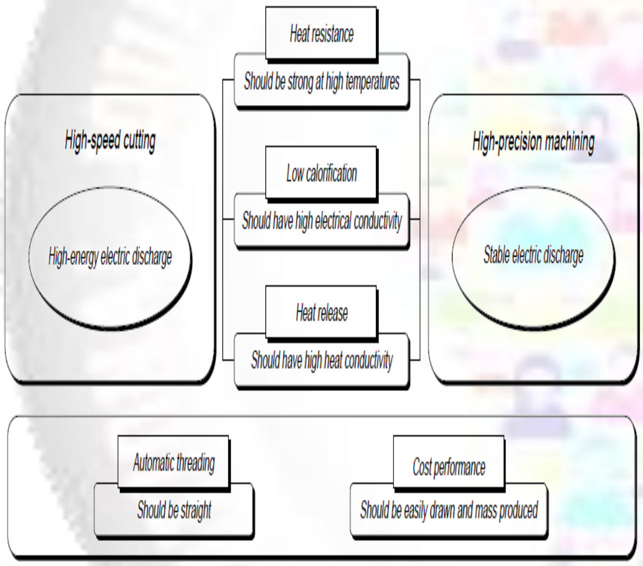


Fig. 2: Performance requirements for the wire electrode [2]

II. Literature Review

Machining is an inherent pre requisite manufacturing process to shape any machine component. Extensive research in the field of WEDM has been done which led to better understanding of the response parameters like metal removal rate, surface finish etc. by employing different combinations of input parameters. The key interest of scientists and technologists has been the development of efficient generators and wire electrodes which led to higher removal rates and better surface finish. This has led to development of WEDM machines with numerical and adaptive controls. Aoyama et al. (1999) had described the development of coated wire electrode to achieve high speed cutting and accurate machining. The new wire electrodes consist of a thin copper zinc alloy layer and core material with high resistance and high electrical conductivity. Two types had been developed: one is called "High – Falcon" (HIF) and is a copper alloy coated with a single phase brass layer. It is applicable when users want high cutting speed and accuracy. The other is called "High-Eagle" (HIE) and is a copper alloy coated with a double-phase brass layer. It is applicable for widespread use when users want faster cutting, but do not require as high accuracy. Ebeid et al. (2003) designed a knowledge-based system (KBS) to select an optimal setting of process parameters and diagnose the machining conditions for WEDM. The system allowed a fast retrieval for information and ease of modification or of appending data. The sample results for alloy steel 2417 and Al 6061 of the various twelve tested materials were presented in the form of charts to aid WEDM users for improving the performance of the process. Huang and Liao (2003) presented the use of grey relational and S/N ratio analysis, for determining the optimal parameters setting of WEDM process. The results showed that the MRR and surface roughness are easily influenced by the table feed rate and pulse on time. Tosun et al. (2003) investigated the effect of the cutting parameters on size of erosion craters on wire electrode. Brass wire of 0.25 mm diameter and AISI 4140 steel was used as tool and work piece materials respectively. The experiments were conducted under the different cutting parameters. Results showed that increasing the pulse duration, open circuit voltage, and wire speed increases the crater size, whereas increasing the dielectric flushing pressure decreases the crater size. The level of importance of the machining parameters on the crater size was determined by analysis of variance (ANOVA) method. Hascalyk et al. (2004) had experimentally studied the effect of WEDM process parameters such as open circuit voltage, pulse duration, wire speed and dielectric fluid pressure on machining characteristics of AISI D5 tool steel. The brass wire was used to perform the WEDM operation. The optical & scanning electron microscopy (SEM) was used for analyzing the metallurgical structure. The conclusion of this study was that the surface roughness increased when the pulse duration & open circuit voltage were increased. The dielectric fluid pressure & wire speed not seeming to have much of influence. The density of cracks in heat affected zone increases with increase in pulse duration & open circuit voltage. Furthermore, the cracks penetrate into heat affected zone depending on pulse energy. Hewidy et al. (2005) carried out WEDM of Inconel 601 material on ELEKTTA MAXICUT 434 WEDM. Brass wire of diameter 0.25 mm was used as electrode. The models for correlating the inter-relationships of various WEDM machining parameters of Inconel 601 material had been established using response surface methodology. Results show that the volumetric metal removal rate can be obtained at peak current (I_P) of 6 A, T_{OFF} of 3 µs wire tension of 7N and water pressure of 3 Mpa. Surface roughness was best achieved at peak current (I_P) of 5A, T_{OFF} of 1 µs wire tension of 9 N and water pressure of 0.5 Mpa. Lin and Lin (2005) reported a new approach for the Optimization of the electrical discharge machining (EDM) process with multiple performance characteristics based on the orthogonal array with the grey relational analysis. Optimal machining parameters were determined by the grey relational grade obtained from the grey relational analysis as the performance index. The machining parameters, namely work piece polarity, pulse on time, duty factor, open discharge voltage, discharge current and dielectric fluid were optimized with considerations of multiple performance characteristics including material removal rate, surface roughness, and electrode wear ratio. Singh and Garg (2009) performed experiments on ELECTRONICA SPRINTCUT WEDM machine. The effect of pulse on time, pulse off time, gap voltage, peak current, wire feed, wire tension on material removal rate of hot die steel (H-11) using one variable at a time approach. Brass wire (CuZn37) with 0.25 mm diameter was used in the experiments. The optimal set of process parameters has also been predicted to maximize the material removal rate. Results showed that value of maximum material removal was 30.24 mm²/min at I_P of 230 A whereas minimum material removal was 12.48 mm²/min at I_P of 50 A. Wire tension had negligible effect on material removal rate. Mahapatra (2010) performed experiments on ROBOFIL 100 high precision 5 axes CNC WEDM, which is manufactured by Charmilles Technologies Corporation. The work piece used in this study was D2 and the wire of 0.25 mm diameter zinc coated copper wire was used as electrode. They derived quadratic mathematical models to represent the process behavior of wire electrical discharge machining. Six process parameters: discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate; were varied in three different levels. Values of material removal rate (MRR), roughness value of the worked surface and kerf had been measured for each of the experimental runs. Predicted data had been utilized for identification of the parametric influence in the form of graphical representation for showing influence of the parameters on selected responses. Grey-Taguchi technique was used to optimize the parameters of wire EDM.

III. Experimental Set-Up

A. Machine Tool: The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at Central Tool Room (CTR), Ludhiana, Punjab, India. The WEDM machine tool has the following specifications:

Parameter	Specification
Design	Fixed column, moving table
Table size	440 x 650 mm
Max. workpiece height	200 mm
Max. workpiece weight	500 kg
Main table traverse (X, Y)	300, 400 mm
Auxiliary table traverse (u, v)	80, 80 mm
Wire electrode diameter	0.25 mm (Standard) ,0.15, 0.20 mm (Optional)
Controlled axes	XY,U,V simultaneous / independent
Interpolation	Linear & Circular
Least command input (X, Y, u, v)	0.0005mm
Input Power supply	3 phase, AC 415 V, 50 Hz

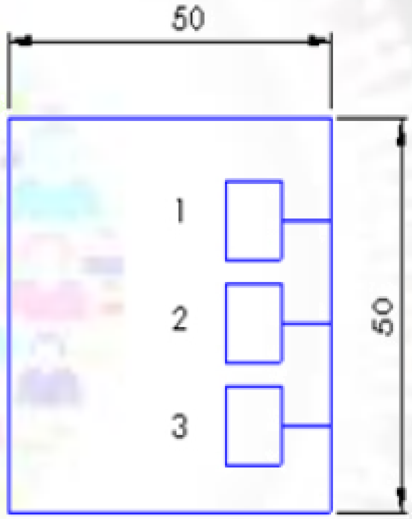
Table. 1: Specifications of Machine Tool

B. Workpiece Material: The AISI D3 die steel plate of 200 mm x 50 mm x 20 mm size has been used as a work piece material for the present experiments. AISI D3 material is mostly used in blanking dies, plastic moulds, shear blades, swaging dies and thread rolling dies.

Constituent	C	Si	Mn	Cr	Fe
%age	2.05	0.25	0.30	11.5	87.95

Table. 2:Chemical Composition of D3 Material

C. Experimental Plan The purpose of this study was to study the effect of type of wire used as wire- electrode for WEDM machining. Also, it was intended to ascertain the range of different parameters required for experimental design methodology used in this work. The Workpiece used was a strip of AISI D3 of dimensions 50mmX 50mm X20mm. Three Square cuts of 10mmx10mmx20mm were cut using three different wires- brass wire, zinc coated and HCS wire. The Workpiece used for this study was shown in figure 3. The experiments were performed on ELEKTRA SPRINTCUT 734 WEDM machine. Various constant input parameters are shown in table 3. The cut is plan to be of a square hole of 10mm * 10mm * 20mm.



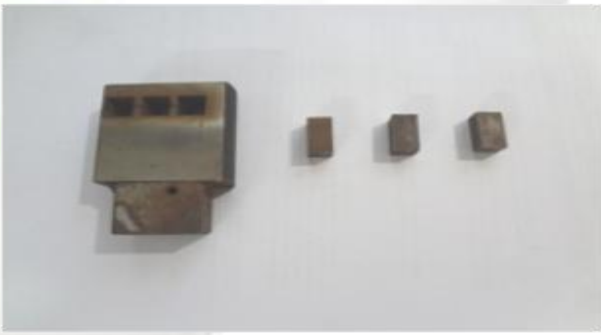


Fig. 3: Photographic view of Workpiece

Parameter	Representation	Value
Pulse on time	T_{ON}	118 units
Pulse off time	T_{OFF}	52 units
Peak Current	IP	230 amperes
Water pressure	W_P	10 units
Wire feed	W_F	6 m/min
Wire tension	W_T	6 units
Servo voltage	SV	50 volt

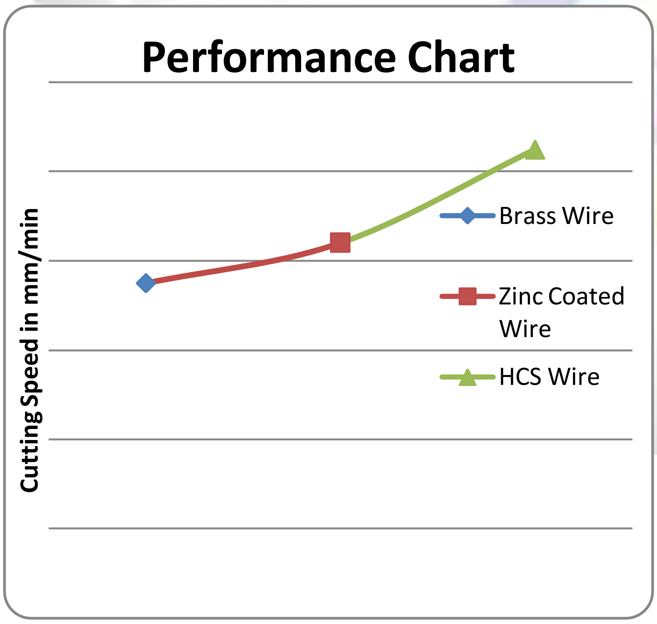
Table. 3: Constant Machine Parameters

IV. Result And Discussion

The cutting speed is an essential performance parameter during any machining operation because it affects the time taken in performing the required operation. Higher the cutting speed, lower will be the cutting time and vice versa. Here the cutting speed and cutting time are compared for the three different wires performing the same job. The comparison statement of the cutting speed of three different wires operated on the same material D3 die steel is shown in the Table 4. Thus it is concluded that zinc coated advances over brass wire from the point of view of improved performance parameters. But Composite wires (Steel wire coated with primary coating of Copper and secondary coating of Zinc) have replaced zinc-coated as the wire of choice for Workpiece. The zinc-enriched outer coating improves flushability, its thickness determines how long it will last in the cut. These high performance wires significantly increase wire EDM productivity but are associated with certain limitations such as high cost, flaking, straightness and possible damage to scrap chopper and may not be used on all the wire EDM machines.

Sample No.	Brass wire	Zinc coated wire	HCS wire
1	0.72 mm/min.	0.88 mm/min.	1.07 mm/min.
2	0.76 mm/min.	0.84 mm/min.	1.06 mm/min.
3	0.79 mm/min.	0.86 mm/min.	1.04 mm/min.
Mean (Cutting rate)	**0.75** mm/min.	**0.84** mm/min.	**1.05** mm/min.
Cutting Time	1'58''	53"38"'	43"21"'

Table. 4: Results of Cutting Rate and Cutting Time



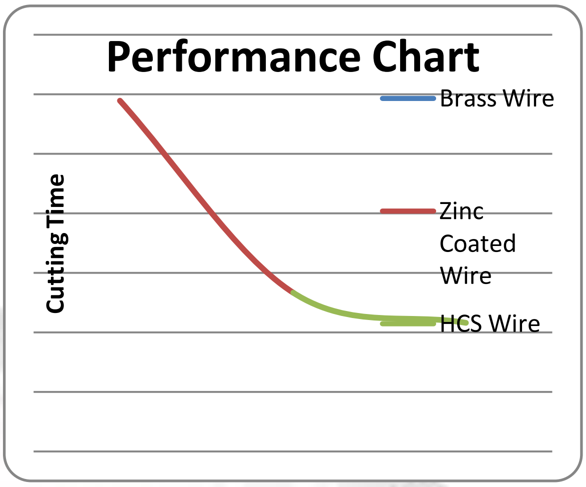


Fig. 4: Effect of wire type on cutting rate and cutting time

The above table and graphs detailed that the cutting speed is maximum i.e. 1.05 mm/min. in case of HCS. Due to high cutting speed, it take minimum time i.e. 43''21''' for the given cut. Cutting rate obtained by HCS wire is 23% (approximately) more than brass wire and 15%more than zinc coated wire. Thus HCS wire shows best performance as compare to Brass and Zinc coated wires. Also the brass wire shows minimum cutting speed results.

V. Conclusions

- D3 die steel is easily cut by wire-EDM operation.
- Cutting rate obtained by HCS wire is 23% (approximately) more than brass wire and 15%more than zinc coated wire.
- The cutting time is minimum while using steel wire having primary coating of copper & secondary coating of zinc as compared to simple brass wire & zinc coated copper wire.

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